A COMPARATIVE PERFORMANCE STUDY OF DOMESTIC ENERGY SIMULATION TOOLS APPLICABLE TO THE HOUSING DESIGN DECISION-MAKING PROCESS

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Abstract

Today, energy simulation tools (ESTs) are readily available being utilised to assist designers (and builders) in achieving energy efficiency targets and fulfilling code regulations. Likewise, the United Kingdom (UK) government recommends the use of the Standard Assessment Procedure (SAP) for energy rating of dwellings. In order to facilitate the assessment procedure, the National Energy Services developed a SAP-based simulation software tool called 'NHER Plan Assessor'. Despite the usability, or ease of application, its accuracy tends to be questioned in view of the limited sources of energy use and climatic condition applied to SAP simulation. Today, a number of similar tools are applied around the globe—e.g. Passive House Planning Package (PHPP) and HOT2000. Unlike the UK's SAP simulation tool, PHPP and HOT2000 have widely been applied to domestic energy simulation beyond their countries of origin—i.e. Germany and Canada, respectively. This study was aimed mainly at demonstrating a way to compare the usability of these ESTs in the design decision-making process. The comparative performance study was carried out using an existing housing prototype called 'ZEMCH 109' in Prestwick, Scotland. This paper identifies the significance of ESTs' information management, agility and adaptability and the correlation to the design decision-making stages, which affect the energy performance of housing. Further investigation on the application of weight evaluation approaches to criteria identified was recommended in this study.

Keywords: *Housing energy simulation tools, NHER Plan Assessor, PHPP, HOT2000, design decision-making process.*

Introduction

The drastic acceleration in the population growth and the life expectancy along with the highly increased energy consumption per person has generated the continuous rise of energy demands(Edwards and Hayett 2001).Consequently, the world has been suffering from fuel poverty (Boardman 1991). This is to some extent reflected by the constant increase of energy costs. Clegg (2007) articulates that the necessity for reduction of not only energy consumption, but also greenhouse gas emissions including carbon dioxide (CO_2), which contributes to raising environmental issues, such as global warming. Thus, the link between energy use, CO_2 emissions and global warming is inextricable. In order to mitigate global warming, the ‘Kyoto Protocol’ was introduced in Kyoto, Japan, on 11th December, 1997, linked to the United Nations Framework Convention on Climate Change (Breidenich, Magraw and Rowley 2013). This protocol set targets for reduction of CO_2 emissions and agreed sanctions for those who fail to meet the targets. Consequently, Scotland is planning to reduce its CO_2 emissions by 80%by 2050in reference to the 1990levels,having an interim target to reduce the emissions by at least 42% by 2020 (The Scottish Government 2012). The residential sector was responsible for around 24% of UK greenhouse gas emissions in 2011, with 15% (74 million tonnes) of all CO_2 emissions (Department of Energy & Climate Change 2013). Therefore, the UK government (excluding Scotland today) has implemented the ‘Code for Sustainable Homes’, which is an environmental assessment method for rating and certifying the performance of new homes (Communities and Local Government 2010). The ‘European Union energy label’ is another environmental performance standard implemented in European Nations including the UK (Department for Environment, food and Rural Affairs 2013). It is a legible colour scheme that ranks products’ energy saving levels with the aim to encourage consumers towards the energy efficient choice.

‘The Government’s Standard Assessment Procedure for Energy Rating of Dwellings’(SAP) is a system adopted by the UK Government as the method of calculating the energy performance and CO_2 emissions of self-contained dwellings (of any size and any age) and it is based on the energy costs associated with: space and water heating, ventilation and lighting (BRE 2011). SAP can be utilised at both initial and final stages of design decision-making. The following section revisits general meanings of the housing design decision-making process.

Housing Design Decision-making Process

The housing design is based on a methodology, which helps the designer to understand how to proceed from the past and present to a forecast of the future (Brawne 2003). This process involves ideas and information, which require successive looping steps or stages and each aims to achieve more resolution than the previous one (Pressman 2012). Pressman (2012) states that the cognitive elements of design process may be viewed as follows:

- **Problem definition**: it includes functional requirements and relationships in qualitative and quantitative terms. Project budget, time schedule and objectives are those that can be considered to be part of the concerns.
- **Information gathering**: it aims to examine project precedents, construction techniques and identifies applicable codes and regulations as well as the site conditions.
- **Analysis**: it is a process to evaluate the problem identified and aims to trigger design ideas translating the project data into graphic representation.
- **Systematic to diagrammatic schemes**: this is the step to establish design concepts and strategies aiming to develop the project programme related to the

site conditions, circulation patterns, environmental impacts and design aesthetics.

- **Schematic design development**: this process intends to convert design concept strategies into the experience of the building in question. It includes the selection of building materials and systems as well as construction technologies and performance.
- **Soliciting and responding to critical feedback**: it is a step of continuous improvement for the design solutions towards the project resolution.

These cognitive elements of design process can simply fall into the following stages:

Early conceptual design stage: this is an explorative phase (Xu, Hendrickson and Hettwer 2006). It encompasses design organisation techniques such as brainstorming, flow charts, modelling and sketching to help visualise the conceptual design (Brawne 2003). The aforementioned problem definition, information gathering, analysis and systematic to diagrammatic schemes elements may be included in this stage.

Final design detailing stage: it is characterised by verifying design solutions through a feedback loop that aims to fulfil the project's demands and requirements (Angelil and Hebel 2008). This stage may include the aforementioned schematic design development and soliciting and responding to critical feedback elements.

To examine the building energy performance, ESTs tend to be applied at the final design stage alone today. However, in order to make proper design decisions towards energy efficiency in building, ESTs should be utilised at the early conceptual design stage as well (Hayter, Torcellini and Hayter 2001). Moreover, ESTs can also contribute to securing thermal comfort at optimal operating energy costs.

Housing designers (and homebuilders) are relatively familiar with environmental issues arising today and they have begun to approach the building simulation field (Attia, Beltran and De Herde 2009). However, seemingly, they tend not to comprehend how to incorporate the simulation results into a proper design decision-making process, although ESTs are adequate to support early stage design decision-making (Bambardekar and Poerschke 2009). With the intention of facilitating the SAP assessment procedure, the National Energy Services developed an EST called 'NHER Plan Assessor'. The software is recognised by the UK government for assessing the energy efficiency of new-build homes and it is approved for issuing Energy Performance Certificates (National Energy Services 2013). The aim of this study is to investigate strengths and weaknesses of this SAP based software and its usability in the housing design decision-making process. In order to identify the aforementioned strengths and weaknesses, this study compares NHER Plan Assessor with two different ESTs selected – i.e. Passive House Planning Package (PHPP) and HOT2000. These tools were selected because of their similarities with NHER Plan Assessor. These two tools are widely recognised worldwide being utilised to verify the delivery of energy efficient homes called 'Super-E' and 'Passive house'.

Energy Simulation Tools Selected

NHER Plan Assessor: it is the EST developed by the National Energy Services to facilitate the SAP (National Energy Services 2013). It is specifically designed to cover the energy rating of dwellings in the UK. The EST is inapplicable to the energy rating of dwellings outside the UK. The version used for this study is the NHER Plan Assessor version 5.4.2.

The NHER Plan Assessor data can be exported into Excel or XML format (National Energy Services 2013). The simulation result scan instantly be showed on the computer screen and the data can be processed into SAP sheets that are used for verification by building authorities (Fig.1).

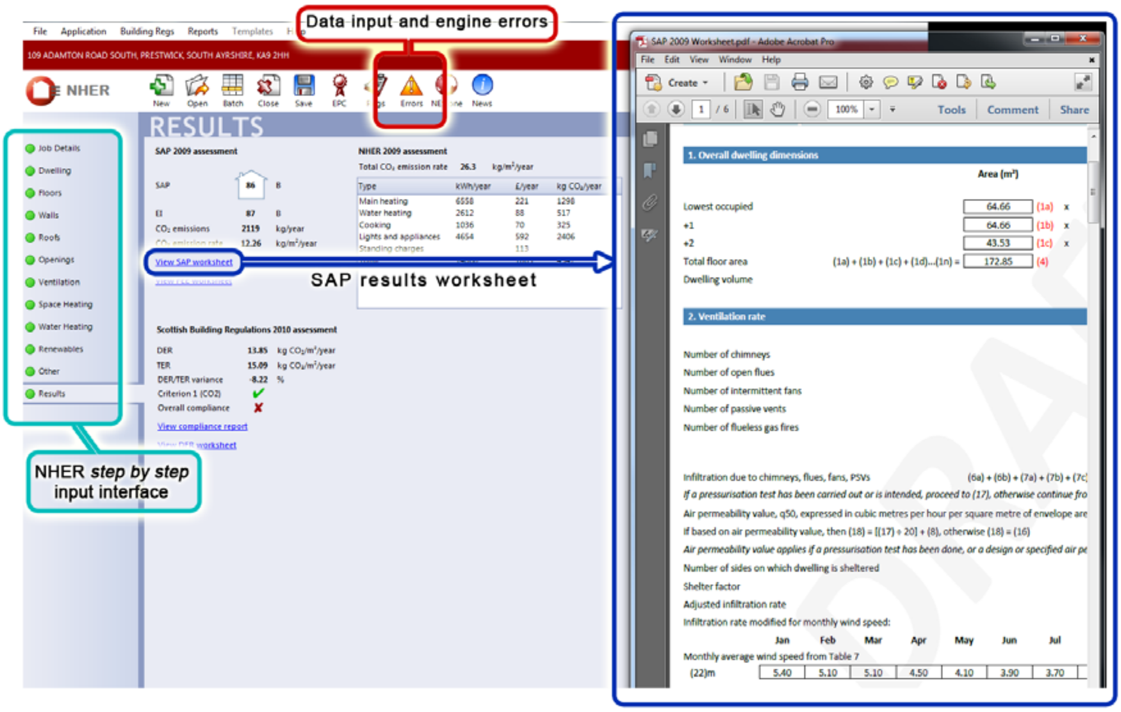

Figure 1: NHER Plan Assessor input interface and result output

This EST is characterised by user-friendly interface and the use of a traffic light colour system, errors and missing data facilitate the operation (Fig.2).

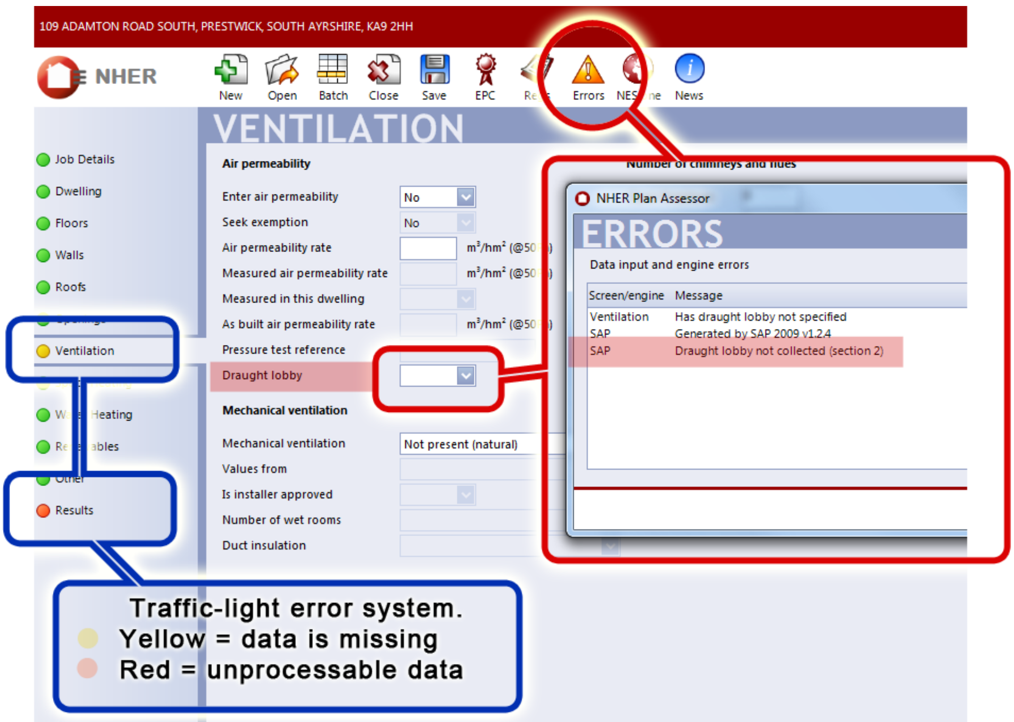

Figure 2: NHER Plan Assessor interface showing the traffic light system to detect errors

The key strengths of NHER Plan Assessor were identified as follow:

- A regularly updateable product library for heating and ventilation systems.
- User-friendly interface.
- Established default component options.
- Instantly signalled error notification.

The weaknesses were:

- Limited energy sources applied to the calculations.
- Inapplicability to housing outside the UK.
- No interactive graphic images that instantly visualise the energy use profile.
- No heating and cooling load estimates in addition to the energy demands.

Passive House Planning Package (PHPP)*:* It is the EST created and operated by the Passive House Institute, applied mainly for verifying domestic and non-domestic buildings in European countries today as 'Passive houses' (Passive House Institute 2012). This certificate refers to the voluntary energy efficient buildings that reduce its ecological print. This study utilised the PHPP version 7. PHPP requires Microsoft Office software to be able to run, because it is based on an Excel worksheet (Fig. 3).

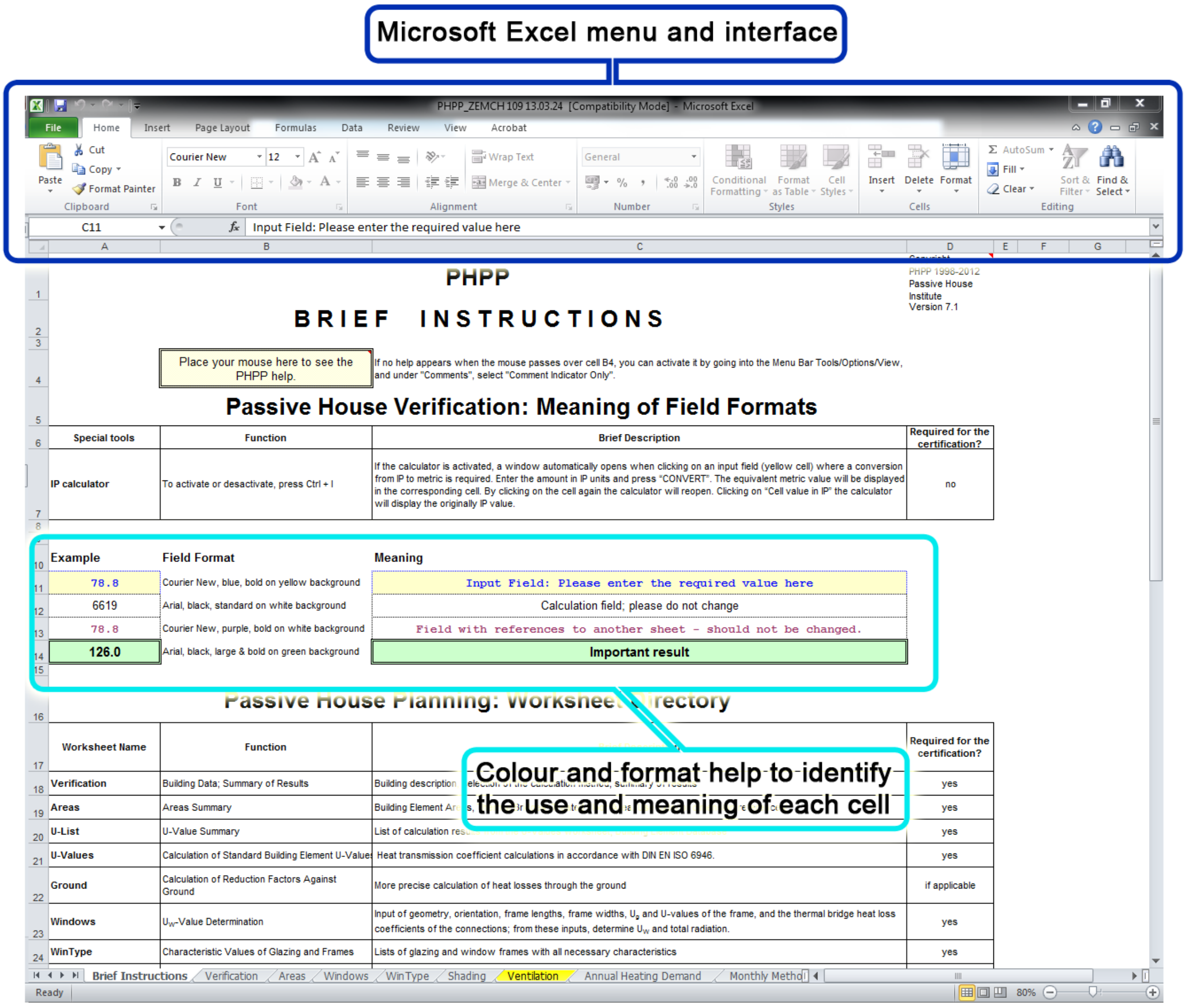

Figure 3: PHPP interface based on an Excel worksheet

The PHPP interface combines input and output in the same worksheets, which facilitate interaction between the data input and the graphical representations (Fig.4).

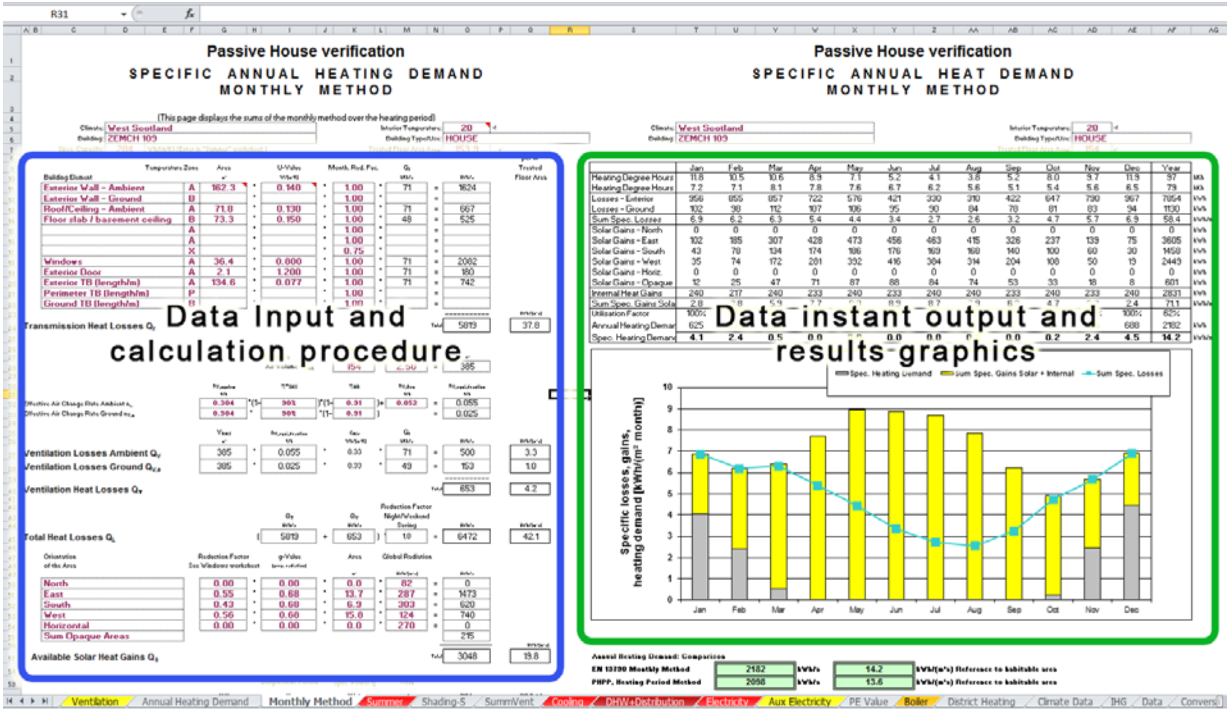

Figure 4: PHPP monthly heat loss profile

The key strengths of PHPP were identified as follow:

- Use of widely applied MS Excel worksheets.
- Interactive graphic images that instantly visualise the energy use profile.
- High level of customisability.
- Global scale applicability.
- Heating and cooling load estimates in addition to the energy demands.

The weaknesses were:

- No error signal representations.
- Lack of menus with default component options.

HOT2000: It is the EST that was developed by the Canadian government with the aim to measure the housing energy efficiency (Canada 2013). R-2000 and Super-E homes are verified using this tool nationally and internationally. This study utilised HOT2000 v10.51, which is downloadable for free of charge unlike PHPP and NHER Plan Assessor.

The interface includes multiple choices of default component options and/or user direct input and this helps increase the level of accuracy (Fig.5). Furthermore, HOT2000 interface contains a large number of simple illustrations that also allow the users to choose the default options so as to mass-customise the configurations and simulate the energy consumption (Fig.6).

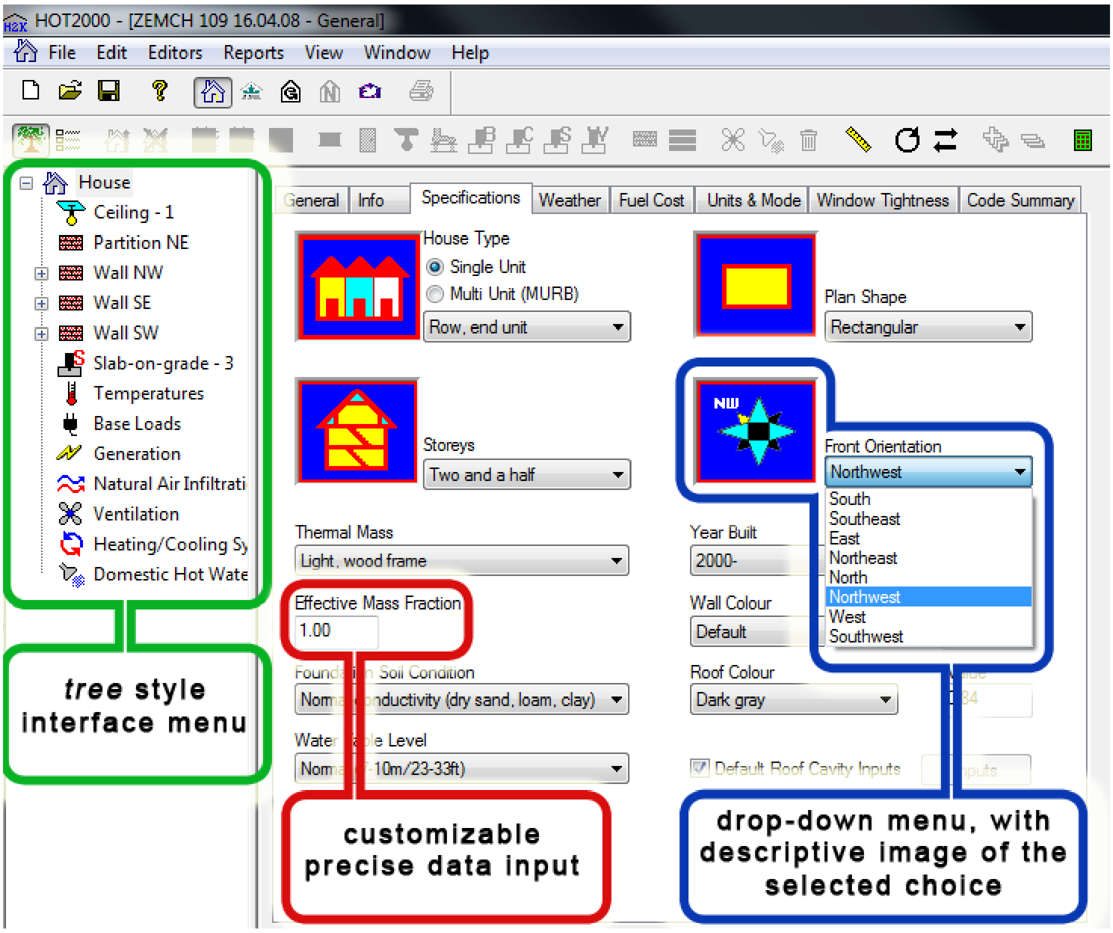

Figure 5: HOT2000 input interface

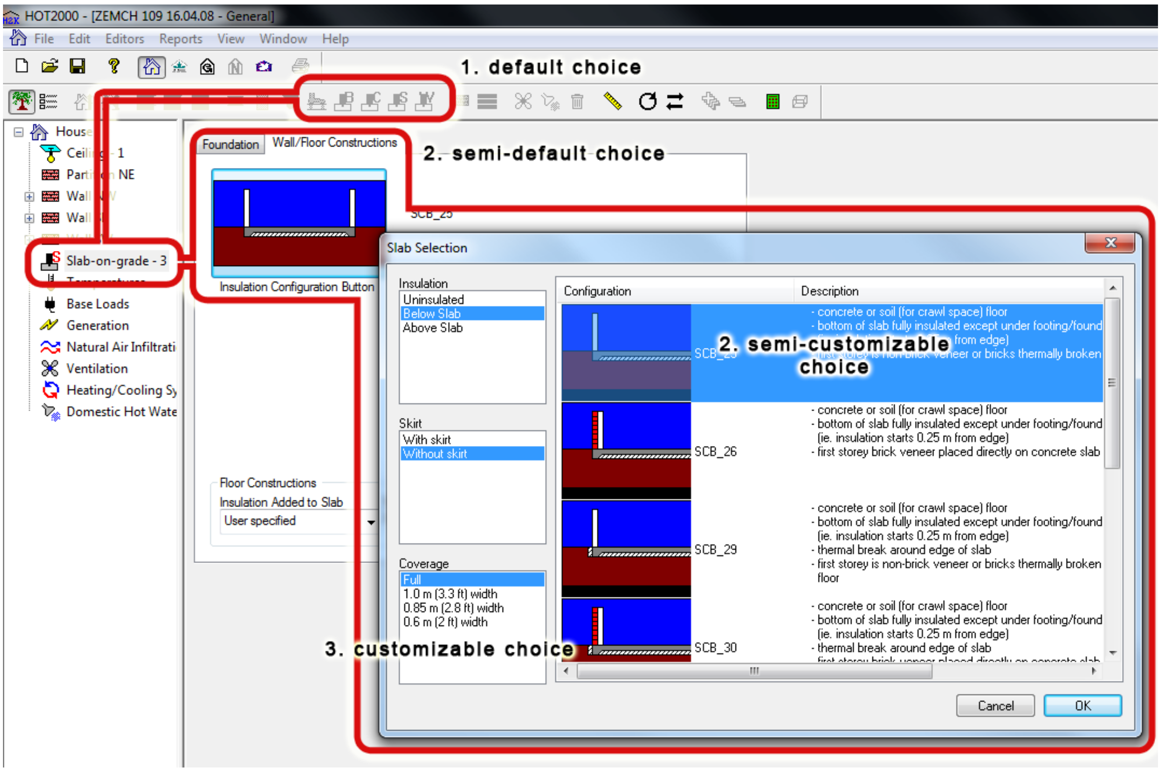

Figure 6: HOT2000 mass-customisable default illustrations

The key strengths of HOT2000 were identified as follow:

- A large number of default options accompanied by illustrations.
- Error reports.
- Global scale applicability.
- Heating and cooling load estimates in addition to the energy demands.

The weaknesses were:

- No interactive graphic images that instantly visualise the energy use profile.
- Complexity in bespoke user input.

This study consists of testing the usability of selected ESTs by making use of a housing prototype proposed in Prestwick, Scotland. Afterwards, in consideration of literature reviews, evaluation criteria were proposed with the aim to compare the ESTs and identify the levels of usability. The following section describes the housing prototype in question.

ZEMCH 109

This study selected a housing prototype proposed NRGStyle in partnership with the Mackintosh School of Architecture and it was intended to be built in Prestwick, Scotland, which falls into a cool climate region (Figs.7&8). It was planned to be a “Zero Energy Mass Custom Home” (NRGstyle 2013). The prototype encompasses a number of passive design techniques as well as advance renewable energy technologies. The application of a passive design approach to housing contributes to operating energy savings which in turn affect the costs (Williams 2012).

Figure 7: South west facade image of ZEMCH109

Figure 8: ZEMCH109 site

The design parameters taken to test the selected ESTs are as follows:

- Latitude: 55-30N, longitude: 004-35W, elevation: 20 m.
- End terrace house.
- 3 storeys.
- Rectangular plan.
- South-east and north-west elongated facades.
- Family structure: 3 adults and 2 children.
- 1 extract fan in the kitchen and 2 fans in restrooms.
- Ventilation air change rate of 0.60 h^{-1}.
- No mechanical ventilation heat recovery system.
- Econoflame main gas boiler with 88.9% efficiency.
- 113 litter hot water tank.
- 25 mm foam insulation material over pipes.
- No cooling mechanical system.
- Gas cooker.
- 1 dishwasher
- 1 washing machine.
- 1 tumble dryer.
- 1 refrigerator.
- 100% CFLs with an average power of 11W per bulb.

Furthermore, as-designed U-values of building components applied to the house are described below (Table 1).

Table 1: Proposed U-values of building materials applied

Building Components	U-values (W/m^2K)
External wall	0.14
Sealed solid party wall	0.00
Warm roof	0.13
Slab on grade floor	0.15
Windows	0.80
Entrance door	1.20

The EST assessment result of delivered energy consumption is tabulated below (Table 2).

Table 2: Assessment results of selected energy simulation tools

	Delivered Energy Consumption (kWh/year)
NHER Plan Assessor	10,371.77
HOT2000	11,473.20
PHPP	12,166.77

Comparative analysis of ESTs selected

Contemplating the aforementioned ZEMCH 109 design parameters, the selected ESTs were compared using the following criteria proposed in view of the literature reviews:

- **Information management**: it is an evaluation category that aims to rate the level of management for entering, processing and presenting data (Attiaa, Hensen and Beltrán 2012).

- **Agility**: it is an evaluation category that aims to rate the tools' capability for the prompt response to the parametric changes required for interactive design decision-making.

- **Adaptability**: it is an evaluation category that aims to rate the level of allowance to flexibly adapt the design parameters that help assess energy and environmental performance.

Based on the evaluation criteria proposed, as described above, the usability of each EST selected was analysed in a comparative manner. The assessment extended subcategories in view of the data input method—i.e. defaults and user input. The denotation of each is described below:

D: Default input.
U: User input.

Moreover, to evaluate each category, the following scale was used:

0: Not applicable.
1: Minimum level of inclusion.
2: Medium level of inclusion.
3: High level of inclusion.

The assessment results of the 'Information Management' category can be found below (Fig.9 and Tables 3&4).

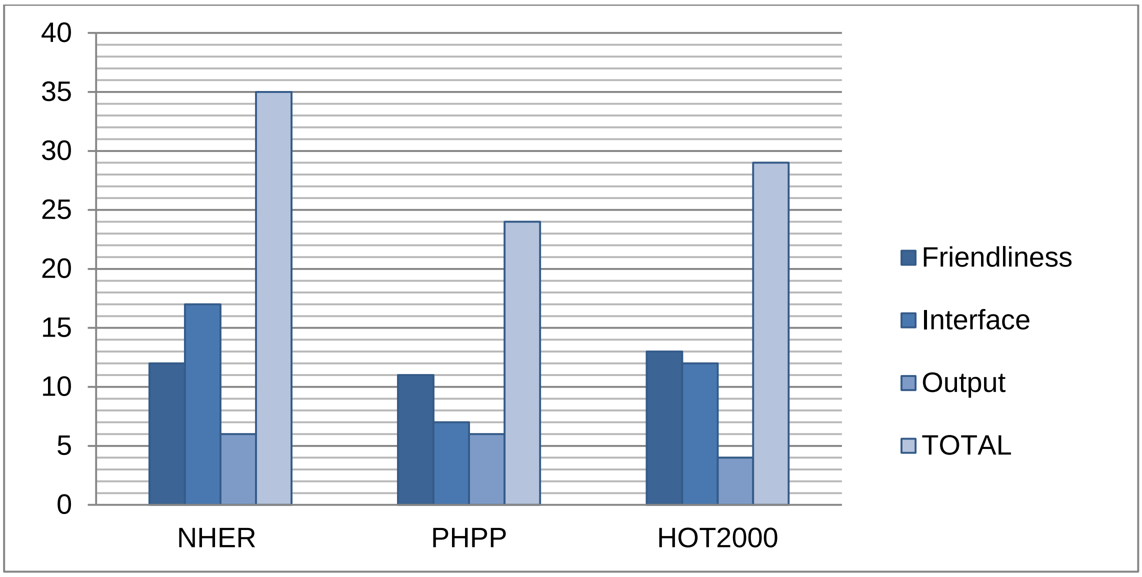

Figure 9: Information management comparison chart

Table 3: Information management comparison table summary

Information management	Summary	NHER	PHPP	HOT2000
	Friendliness	12	11	13
	Interface	17	7	12
	Output	6	6	4
	TOTAL	**35**	**24**	**29**
	Level of default input	30	20	23
	Level of customisability in operation	5	4	6

Table 4: Information management comparison table

Information management		Building Energy Simulation Tool	NHER		PHPP		HOT2000	
		Criteria	D	U	D	U	D	U
	Friendliness	Use of different types of metrics	1	0	1	0	2	0
		User need of environmental background knowledge	3	0	1	0	2	0
		User guide and/or tutorial	2	0	3	0	2	0
		Provision of calculation flow diagram	0	0	1	0	0	0
		Software include a sample file	0	0	2	0	0	0
		Facility to change entries	3	0	1	0	2	0
		Undo/redo tool	0	0	2	0	0	0
		Default options accompanied by illustrations	0	0	0	0	3	0
		Friendly help menu	3	0	0	0	2	0
	Interface	Error Diagnostic	3	0	0	0	2	0
		Input presentation	3	1	1	2	2	2
		Control and navigation	3	1	1	1	1	1
		Mapping internal data	3	3	1	1	2	2
	Output	Inclusion of energy cost estimates	1	0	0	0	1	1
		Flexible selection of output data	1	0	2	0	0	0
		Quality and quantity of instant result graphics	0	0	2	0	0	0
		Mapping results	2	0	1	0	1	0
		Legible format	2	0	1	0	1	0

The assessment results of the 'Agility' category can be found below (Fig.10 and Tables 5&6).

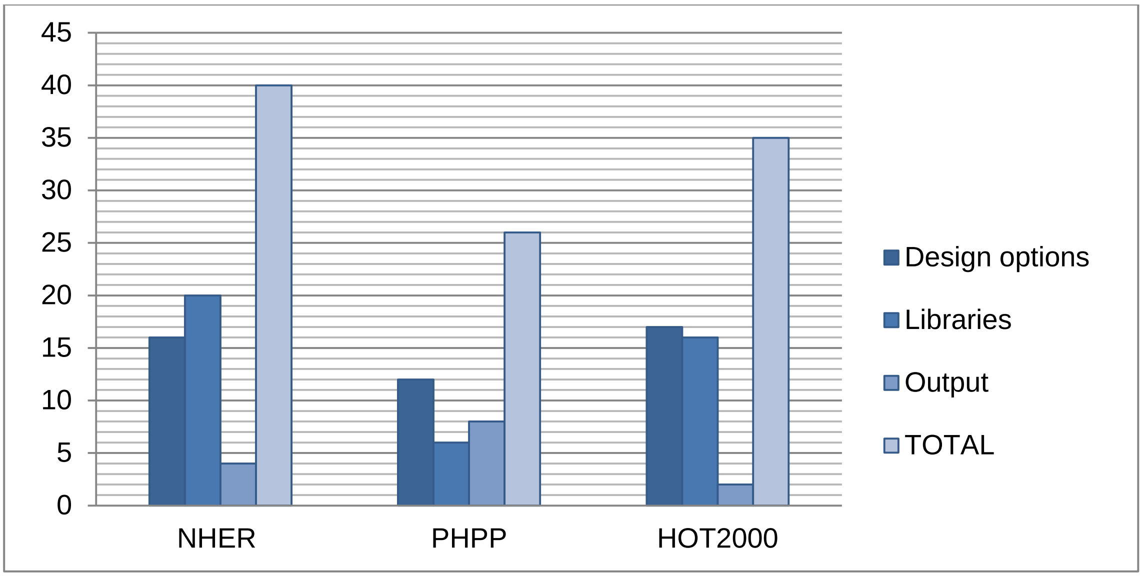

Figure 10: Agility comparison chart

Table 5: Agility comparison table summary

	Summary	NHER	PHPP	HOT2000
Agility	**Design options**	16	12	17
	Libraries	20	6	16
	Output	4	8	2
	TOTAL	**40**	**26**	**35**
	Level of default input	31	3	25
	Level of customisability in operation	9	23	10

Table 6: Agility comparison table

Building Energy Simulation Tool			NHER		PHPP		HOT2000	
		Criteria	D	U	D	U	D	U
Agility	Design options	Weather data input	3	1	1	1	2	1
		Building plan and type	2	0	0	1	2	0
		Number and characteristics of occupants	0	0	1	1	3	0
		Thermal mass input	2	2	0	2	2	1
		Building service input	2	0	1	2	2	1
		Thermal bridge input	3	1	0	2	3	0
	Libraries	Materials for building envelope	3	1	0	1	2	1
		Ventilation products	3	1	0	1	2	1
		Heating systems	3	1	0	1	2	1
		Cooling systems	0	0	0	1	2	1
		Domestic hot water systems	3	1	0	1	1	1
		Renewable energy technologies	3	1	0	1	1	1
	Output	Energy consumption and CO2 emissions	2	0	0	3	1	0
		Instant results	0	0	0	2	0	0
		Notice for regulation compliance	2	0	0	3	0	1

The assessment results of the 'Adaptability' category can be found below (Fig.11 and Tables 7&8).

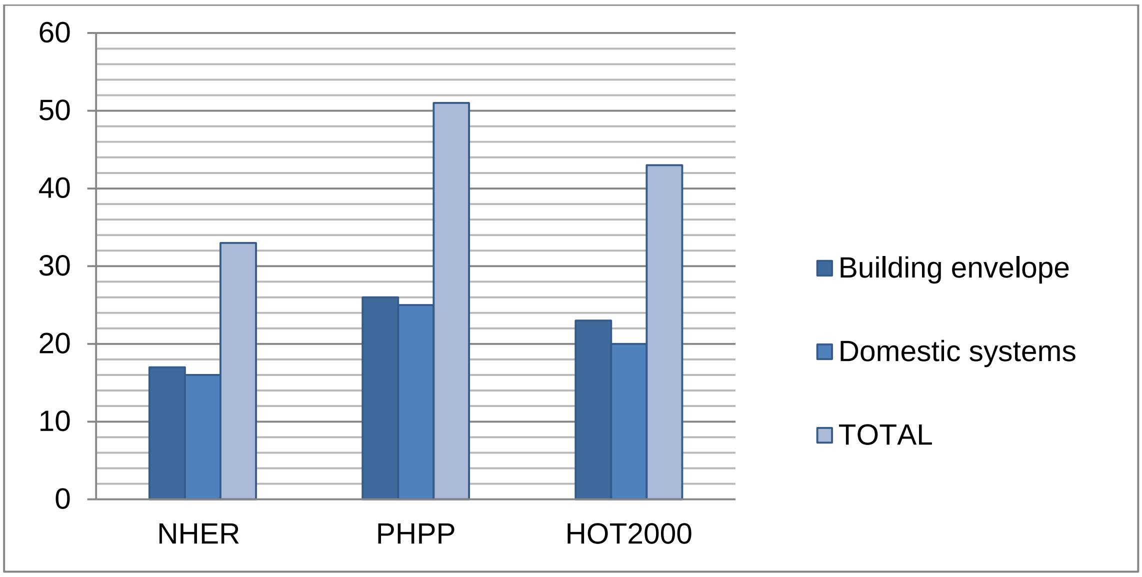

Figure 11: Adaptability comparison chart

Table 7: Adaptability comparison table summary

Adaptability	Summary	NHER	PHPP	HOT2000
	Building envelope	17	26	23
	Domestic systems	16	25	20
	TOTAL	**33**	**51**	**43**
	Level of default input	21	11	23
	Level of customisability in operation	12	40	20

Table 8: Adaptability comparison table

Adaptability		Building Energy Simulation Tool	NHER		PHPP		HOT2000	
		Criteria	D	U	D	U	D	U
	Building envelope	Wall characteristics including U-values	1	1	1	3	1	1
		Roof characteristics including U-values	1	1	1	3	2	1
		Window size and location	2	2	1	3	2	1
		Window glazing and framing	2	1	2	3	1	0
		Door characteristics including U-values	2	1	1	3	1	1
		Building envelope colour selection	0	0	0	1	2	0
		Window inclination	1	0	0	2	2	2
		Thermal zone differentiation	0	1	0	0	0	1
		Basement types	1	0	0	2	3	2
	Domestic systems	Air permeability	2	1	1	3	2	2
		Ventilation	2	1	1	3	2	1
		Heating systems	2	1	1	3	1	2
		Cooling systems	0	0	1	3	1	1
		Domestic hot water systems	2	1	0	3	2	1
		Manipulation and description of Renewables	2	1	0	2	1	2
		Building service load distribution	1	0	1	3	0	2

In view of the aforementioned evaluation criteria, the assessment results of the ESTs selected were compared. In order to help grasp the outcomes at a glance, a comparative diagram was developed as follows (Fig. 12). In the light of the information management criterion, NHER Plan Assessor reached the highest level among the selected ESTs, while PHPP was considered to be the lowest. Regarding the agility criterion, the same tendency was observed. However, PHPP achieved the highest level in terms of the adaptability criterion, while NHER Plan Assessor was estimated at the lowest.

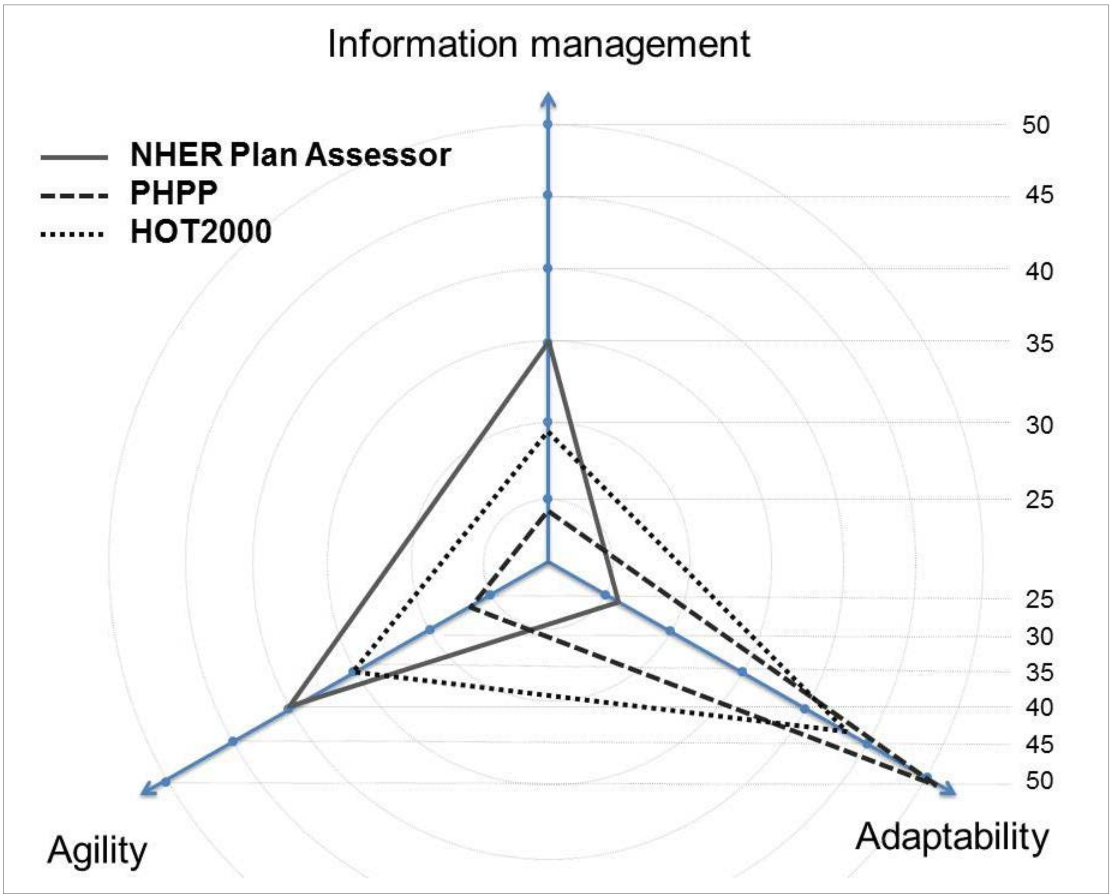

Figure 12: Selected ESTs summary comparison chart

Conclusions

The high level of the information management criterion studied may facilitate housing designers with or without environmental design experience to use energy simulation tools (ESTs) for the assessment of energy efficiency performance during the design decision-making process. The agility to use ESTs permits the completion of the assessment in a short period of time and this allows the users to examine different design alternatives. The choice of design alternatives affects housing energy efficiency performance; therefore, it is preferred to be carried out at the early design decision-making stage. The applicability of the tools to worldwide contexts may be desirable to accommodate a wide range of projects around the globe. Moreover, the high level of the adaptability (and customisability) somewhat links to the accuracy of energy simulation. In fact, the energy simulation of the ZEMCH 109 housing prototype demonstrated indicates that the estimate using PHPP, which was rated at the highest level of adaptability, resulted in the largest delivered energy consumption (12,166.77 kWh/year). On the other hand, HOT2000 with the second highest level of adaptability followed the PHPP (11,473.20 kWh/year), while NHER Plan Assessor with the lowest adaptability level came into the third place (10,371.77 kWh/year). Nonetheless, the accurate simulation may be relevant to the definitive selection of housing components that needs to be made at the final design and purchase decision-making stage.

This study was aimed mainly at demonstrating a way to compare the usability of ESTs in the design decision-making process. However, each project and stakeholder may have different viewpoints, needs and desires. Accordingly, some weight evaluation approach to criteria identified in this study should be incorporated in order to accommodate the diversity of housing projects. Therefore, the EST assessment model demonstrated in this paper may need to be studied further.

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